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## Reputation and the Control of Pollution

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**Abstract:** This paper investigates the effectiveness of reputation in inducing a polluting firm to self-regulate its emissions when consumers have imperfect information. In particular, we ask to what extent must consumers reward and punish the firm before it chooses self-regulation as its dominant strategy? We find that if payoffs in the stage game are such that both the consumer and the polluting firm have beliefs that are consistent with each others' behaviors, then the firm has a positive probability of playing clean in each period of a finite game. Further, we find that a weak reward/punishment scheme may have an adverse effect on the environment, and that there are both environmental and welfare gains associated with strengthening the scheme.

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## 1. **Introduction**

Is it possible to control pollution without the involvement of a regulator? On the surface, this question seems heretical. Even though the most appropriate type of regulation for any given pollution problem is still a topic of debate, both experience and theory seem to dictate some form of involvement by a regulatory authority. Indeed, the debate over environmental regulation is typically bounded by the hierarchical questions of : (1) under what conditions are market-based incentives more efficient than command-and-control standards; and (2) assuming that these conditions exist, then whether taxes, transfers, marketable permits, or some combination therein are the preferable mechanisms. As a result of this bounded debate, the basic question has yet to be adequately answered of whether there is a more radical alternative to the ideology of regulator-centric control than these market mechanisms. We show in this paper that such a theoretical alternative may exist. When an unregulated (i.e. “dirty”) firm’s reputation both matters and can be updated over time, repeated interactions between the firm and its consumers can lead to self-regulation (i.e. the dirty firm becomes “clean”), even when both the consumers and firm have imperfect information about each other’s payoffs.

We find that if payoffs are such that both the consumer and the polluting firm have beliefs that are consistent with each others’ behaviors, then in a sequential equilibrium the firm has a positive probability of behaving clean in each period of a finite game. Further, a weak reward/punishment scheme (i.e. a scheme whereby the consumer does not effectively utilize information about the firm’s previous emissions levels to alter his demand) may have an adverse effect on the environment; thus there are both environmental and welfare gains associated with

strengthening the scheme.<sup>1</sup> This is good news, as it implies a less active, and presumably less costly, role for the regulating authority. Theoretically speaking, the authority's role might best be relegated to solely pollution monitoring and information dissemination, rather than promulgating technology standards, setting new tax rates, determining permit quotas, or making transfers (each of which typically invokes a weighty political process).

Realistically, will consumers utilize information about firm-level emissions to alter their consumption decisions? How likely are polluting firms to believe that consumers will do so, and thus alter their emissions strategies?<sup>2</sup> Empirical research devoted to answering these questions has thus far been too mixed to draw any steadfast conclusions.<sup>3</sup> Concomitant with a relatively small amount of empirical research is a dearth of theoretical analysis. For instance, Kennedy, et al. (1994) argue that due to market failure, there is a role for public information provision if no other policy instruments are available. In their paper, market failure arises from an unpriced external benefit associated with an "information purchase" by any given consumer, which in turn leads the market to under-provide information. What ultimately matters, however, is how firm - not consumer - behavior is changed through information provision. Further, Kennedy et al.'s model is static and thus incapable of addressing the overriding question of how firm behavior changes over time in response to information provision.

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1 As will be discussed in greater detail in Section 5, "strength" in this sense implies not only the type of information provided to consumers by the monitoring authorities, but also the inclination of consumers to use this information to distinguish between clean and dirty firms.

2 Several studies have confirmed that *investor* reactions to the release of pollution data and announcements of lawsuits and suit settlements can significantly reduce stock market returns for polluting firms. For instance, see Lanoie, et al. (1998), Konar and Cohen (1997), Badrinath and Bolster (1996), Hamilton (1995), and Laplante and Lanoie (1994).

3 For examples, see Nimon and Beghin's (1999) analysis of the retail apparel industry, Foulon et al.'s (2000) study of the public disclosure strategy adopted by the province of British Columbia in Canada, and Arora and Cason's (1995) study of the EPA's 33/50 program to encourage voluntary reductions in toxic releases.

The framework adopted by Cavaliere (2000) is directed toward answering this question, and comes closest to the sequential-equilibrium concept used in the present paper. Cavaliere considers the interactions between a monopolist and a consumer who choose environmental quality with imperfect information. His model is developed for the two-period case. The firm's dominant strategy in the second period is to produce the dirty good, while consumers randomize between dirty and clean goods if the firm produced the clean good in the initial period. Randomization of consumer choices in the final period has a positive effect on the firm's two-period payoffs, thus it may be in the firm's interest to produce the clean good in the first period and therefore gain the reputation of being a clean firm. A shortcoming of Cavaliere's model is its inability to extrapolate beyond the two-period case and thus test whether or not - and for how many periods - a dirty firm might enhance its reputation by choosing self-regulation as its dominant strategy. Our model builds on Cavaliere's by developing a more general repeated-game framework that extends beyond two periods.

Another interesting paper, by Arora and Gangopadhyay (1995), offers a theoretical explanation for why some firms over-comply with minimum environmental standards. Using a full-information two-stage duopoly model, where in the first stage firms choose their level of cleanup and in the second stage they engage in price competition, the authors show that an a priori clean firm will over-comply when the following two conditions hold. First, due to a presumed availability of public information, consumers are able to *perfectly* distinguish between the clean and dirty firms based on their respective levels of cleanup. Second, an income differential among consumers is sufficient to support demand for cleaner products at higher prices (i.e. the market is segmented by income level). Arora and Gangopadhyay find that publicly provided information can induce more cleanup by some firms when that information

enables consumers to perfectly determine the emissions behavior of firms.<sup>4</sup>

Applying Backus and Driffill's (1985) repeated-game solution technique to the problem of environmental regulation, we find that under certain circumstances a polluting firm selects self-regulation as its dominant strategy merely by internalizing the forward effect of its reputation as a clean or dirty firm (or, in terms of Arora and Gangopadhyay the dirty firm voluntarily over-complies). Unlike in Arora and Gangopadhyay, this result occurs without consumers having perfect information. Rather, consumers are uncertain of the actual intentions of the firm, and therefore must rely solely on the firm's past behavior in updating their beliefs about the future. Further, a segmented market is unnecessary for self-regulation.

The sequential-equilibrium framework enables us to show under what circumstances a firm is induced by an uncertain consumer to consider the reputational effects of its current and future emissions levels, while satisfying the property of dynamic consistency. In other words, the firm always finds it optimal to stick to its initial plan, whether or not the plan involves becoming clean.<sup>5</sup>

Previous studies using static models have offered compelling rules that minimize the role of the regulatory authority in controlling pollution, but these rules do not portend to minimize the regulator's role as substantially as that which evolves from the sequential equilibrium

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4 Harrington (1998) also finds a theoretical justification for over-compliance. In his repeated-game model, over-compliance occurs in the sense that a firm may have an incentive to comply with regulations even though its compliance cost each period exceeds the expected penalty for violation. What drives this result is the ability of the regulator to segment its enforcement policies into low (i.e. non-aggressive) and high (i.e. aggressive) categories. A firm currently in the high category therefore has incentive to comply, regardless of its compliance costs, in order to be returned to the low category.

5 Kreps and Wilson (1982a) show that this result holds only for perfect and plausible strategies. The property of dynamic consistency is what Harrington (1988) calls a stationary policy.

investigated here.<sup>6</sup> A plethora of regulator-centric dynamic solutions have also been proposed in the literature.<sup>7</sup> However, despite their prescriptions of relatively simple regulatory rules that can lead to reduced levels of pollution, none of these studies consider an equilibrium solution that relies entirely on uncertain consumers' abilities to induce self-regulation on the part of the polluting firm. As this paper shows, the mechanism of providing consumers with enough (albeit imperfect) information to distinguish between clean and dirty firms can be, theoretically speaking, adequate enough to control pollution. The regulator's goal is solely to provide consumers with information about the firm's emissions rates; information that enables the consumer to form a reputation that is consistent with the firm's performance over time.

The next section provides a brief overview of current policies that rely on information provision and reputation formation. Section 3 introduces the basic model and discusses its equilibrium properties. Section 4 provides examples of how sequential equilibria are determined for two important cases. Section 5 calibrates the model, and solves for its sequential equilibria under three different information scenarios. Section 6 summarizes and discusses the various policy implications of the analysis.

## 2. Policy Background

How feasible is a shift away from the current regulator-centric paradigm toward self-

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<sup>6</sup> c.f. Cornes and Silva (1999), Varian (1994), and Porter (1988).

<sup>7</sup> Studies that concentrate on first-best mechanisms include Benchenkroun and van Long (1998), Baron and Besanko (1984), Spulber (1988), Xepapadeas (1991, 1992), Dockner and van Long (1993), Chichilnisky and Heal (1993), and Loehman and Dinar (1994). Studies either concentrating more or exclusively on second-best outcomes include Jones and Scotchmer (1990), Kambhu (1990), Hoel (1991), Egteren (1992), Lewis and Sappington (1992), and Garvie and Keeler (1994). Caillaud, et al. (1988) provide a comprehensive survey of the literature on regulation under asymmetric information.

regulation? If recent experience is any guide, then it might be feasible for certain classes of externalities under certain market structures. For example, U.S. federal law mandates that the Environmental Protection Agency (EPA) compile information on toxic chemical pollution nationwide in what is known as the Toxic Release Inventory (TRI). Approximately 650 chemicals have thus far been designated for reports under TRI, resulting in approximately 73,000 reports being submitted in 1996 by 21,000 manufacturing facilities and 200 federal facilities (EPA, 2000; Graham and Miller, 2001). TRI information is easily retrievable from the EPA's web site, as well as from the Environmental Defense's (ED) "Scorecard" link (ED, 2000).<sup>8</sup> This information enables consumers to track toxic releases of manufacturing firms into local air- and watersheds, and can therefore shape the reputations that consumers hold of various firms. The EPA has recognized for several years that its role is not only to enforce environmental laws, but also to provide citizens with useful information that will assist them in shifting their consumption habits away from "dirty" goods and polluting firms (EPA, 1988 & 1996).

The feasibility of a shift away from the regulator-centric paradigm has similarly been tested during the past few decades by a growing number of OECD countries, through their experiments with eco-labeling.<sup>9</sup> According to the OECD (1997), eco-labeling has been moderately successful with the individual consumer, although public awareness and attitudes toward eco-labeled products vary significantly across countries and across demographic groups within countries. Also, the various types of eco-labels are believed to have differential impacts

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<sup>8</sup> TRI data has also been disseminated through other EPA programs, such as the 33/50 program (Arora and Cason, 1995), and a variety of popular press outlets (Hamilton, 1995).

<sup>9</sup> Among the more notable eco-labeling programs are the EU Eco-Label Award Scheme, the Nordic Swan, the Swedish Environmental Choice Programme, the Canadian Environmental Choice Programme, the German Blue Angel Scheme, the Japanese Eco-Mark, and the French NF Environment (OECD, 1991).

on consumer behavior. For instance, Type I labels are government-supported, third-party certification schemes that “apply to a small proportion of products in a product category which are determined to have lessened adverse environmental impacts (OECD, 1997).” Type II labels are informative self-declaration environmental claims made by manufacturers, and Type III labels are quantified product information based upon independent verification. Because it is based upon a more rigorous distinction of what is a “clean” product, a Type I label should, all else equal, have a stronger impact on consumer behavior than either Type II or Type III labels. According to the OECD, eco-labeling has become a popular tool to promote environmentally preferable consumption and production patterns. This popularity points to the potential of using information to form reputations of specific companies; reputations that might govern the companies’ future emissions strategies.<sup>10</sup>

### 3. The Basic Model

Payoffs for each period  $t$  of a finite game played between a consumer and any given firm are expressed symbolically in Table 1, where the superscripts on  $\pi$  (profit) and  $U$  (utility) denote the four possible outcomes (e.g. superscript 1 denotes the outcome when the firm behaves clean, but the consumer believes that the firm is dirty; superscript 2 denotes the outcome when the firm

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<sup>10</sup> Although not as formal as the OECD’s eco-labeling schemes, evidence from lower-income countries also points to how reputation formation can govern firm behavior. For example, in their study of water pollution in Indonesia, Pargal and Wheeler (1996) find that even in the absence of any formal regulation, factory-level water pollution is responsive to variables such as local employment shares, population density, worker education and income levels; variables which the authors believe reflect the typical factory’s concern about its reputation. In their study of traditional Mexican brickmakers, Blackman and Bannister (1998) find that “community pressure” can motivate dirty firms to adopt clean technologies, similarly implying a strong reputation effect.



behaves clean and the consumer believes the firm is clean, etc.).<sup>11</sup> For now, we can safely assume that a matrix of actual payoffs indeed exists, which is determined by (1) the quality of information provided to the consumer about the firm, (2) the extent to which the consumer utilizes the information, and (3) the extent to which the firm responds to what it perceives as its reputation (defined in detail below). In Section 5, we suggest a simple general-equilibrium model that yields payoff matrices for different assumptions about these three determinants.

[INSERT TABLE 1 HERE]

It is assumed that neither the consumer nor the firm have common knowledge about the payoffs in Table 1. While the two players know their own respective payoffs, they do not know each other's. However, should it play dirty in any period  $t$ , then similar to Kreps and Wilson (1982b) and Backus and Driffill (1985) we assume that the firm's reputation is blown. In this case, the consumer believes with certainty that the firm is dirty and thus the payoff in cell  $(\pi^3, U^3)$  obtains in all future periods.

As indicated in Table 1, the firm's strategy set includes two possible actions in any period  $t$  - behave clean or dirty. For example, behaving clean might entail voluntary abatement or a self-tax on emissions, while behaving dirty would reflect an absence of these types of actions. The firm can therefore be thought of as choosing a behavioral strategy over these two actions, which maximizes its cumulative expected profit across periods  $t = 1, \dots, T$ .

The consumer's strategy set reflects the level of expected firm cleanliness - entirely clean or entirely dirty. This is an obvious abstraction from reality, where consumers may have a continuum of expected cleanliness levels in their strategy sets (e.g. various levels of partial

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<sup>11</sup> Since payoffs are constant across periods (as opposed to expected payoffs, which vary period-by-period) we have dropped the subscript  $t$  from  $\pi$  and  $U$  in Table 1.

cleanliness), but one that without loss of generality greatly reduces the complexity of the ensuing games described below. An additional simplification in this model is the definition of the consumer's strategy set over beliefs rather than specific actions per se, such as actual purchasing decisions. Since a consumer's actual purchasing decisions can reasonably be considered as perfectly determined by her beliefs, there is no loss of generality in defining her strategy set directly over her beliefs. Further, there is a considerable gain in focus on what characterizes firm behavior in a sequential equilibrium.<sup>12</sup> Therefore, in this framework the consumer chooses a behavioral strategy over her two beliefs about the firm's level of cleanliness that maximizes her cumulative expected utility across periods  $t = 1, \dots, T$ .

Similar to the sub-game perfect equilibrium concept for finite multi-stage games, a sequential equilibrium is solved by backward induction, beginning with the final period  $T$ . An equilibrium is characterized as a set of probabilities and corresponding beliefs and actions for the consumer and firm, respectively, such that neither agent has any incentive to deviate from his behavioral strategy in any period of the game (i.e. the strategies are sequentially rational). To find the sequential equilibrium for this game, we first define the following two probabilities:  $z_t =$  the probability that the consumer believes the firm is clean in a mixed strategy;  $y_t =$  the probability that the firm plays clean in a mixed strategy. The firm's reputation in period  $t$ ,  $\rho_t$ , is then the probability that the firm is clean in period  $t$  given the history of the game up to this point.<sup>13</sup> Similarly, the firm's reputation in period  $t+1$ ,  $\rho_{t+1}$ , is the probability that the firm is clean going into period  $t+1$  given that it has behaved clean up to period  $t$  (therefore,  $\rho_{t+1}$  reflects

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<sup>12</sup> Backus and Driffill (1985) assume a similar strategy set for the consumer in their model of government behavior, where the consumer's actions in any period  $t$  are his beliefs, or expectations, about inflation.

<sup>13</sup> This can alternatively be thought of as the joint probability that the firm is clean going into period  $t$  and that it will play clean in period  $t$

the change, or update, in the consumer's belief that the firm is clean as the game proceeds from period  $t$  to  $t+1$ ). By Bayes Rule, we therefore have

(1)

where  $q_t = \rho_t + (1 - \rho_t)y_t$  represents the fact that the marginal probability of the firm playing clean in period  $t$  is a weighted sum of the probabilities of the firm being clean ( $\rho_t$ ) and not being clean but nevertheless having a probability associated with playing clean that period  $((1 - \rho_t)y_t)$ . At each stage of the game, therefore, the consumer's and firm's strategies specify respective probabilities over beliefs and actions as functions of reputation.

Using the payoffs in Table 1, we are able to calculate the expected final-period  $T$  payoffs to the consumer and the firm, respectively, as

$$E_T(U) = U(z_T, \rho_T, T) \quad (2a)$$

$$E_T(\pi) = \pi(y_T, z_T, T) \quad (2b)$$

where the respective variable sets  $\{z_T, \rho_T\}$  and  $\{z_T, y_T\}$  enter linearly in the consumer's and firm's period  $T$  expected payoffs.<sup>14</sup> From (2a), the consumer plays

(3)

for any given  $\rho_T$ , where the sub-scripted letter on function  $U$  represents the partial derivative with respect to that letter. In other words, if  $E_T(U)$  is increasing in  $z_T$ , then in the game's final period

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<sup>14</sup> The specific payoffs from each of the cells in Table 1 are subsumed in expressions (2a) and (2b), and all other expressions for expected utility and profit that follow.

the consumer will believe that the firm is clean with certainty. If  $E_T(U)$  is decreasing in  $z_T$ , then in the final period the consumer will believe that the firm is dirty with certainty. Only when  $\rho_T$  is such that  $E_T(U)$  is unaffected by changes in  $z_T$  will the consumer randomize in period  $T$ .

Similarly, from (2b) the firm plays

(4)

for any given  $z_T$ . In other words, if  $E_T(\pi)$  is increasing in  $y_T$ , then in the game's final period the firm behaves clean with certainty. If  $E_T(\pi)$  is decreasing in  $y_T$ , then in the final period the firm behaves dirty with certainty. Only when  $z_T$  is such that  $E_T(\pi)$  is unaffected by changes in  $y_T$  will the firm randomize in period  $T$ .

Moving backward one period to  $T-1$ , the expected two-period payoffs to the consumer and firm, respectively, are:

$$E_{T-1}(U) = U(z_{T-1}, y_{T-1}, \rho_{T-1}, T-1) \quad (5a)$$

$$E_{T-1}(\pi) = \pi(y_{T-1}, z_{T-1}, \rho_T, T-1) \quad (5b)$$

where the respective variable sets  $\{z_{T-1}, \rho_{T-1}\}$  and  $\{y_{T-1}, \rho_T\}$  enter linearly in the consumer's and firm's period  $T-1$  expected two-period payoffs. Thus, the same conditions as expressed in (3) and (4) for period  $T$  apply respectively to the consumer and firm in period  $T-1$ , which generalizes for each period  $t$ . These results are summarized conveniently in the following two theorems.

**Theorem 1:** *If  $\rho_t$  is such that  $E_t(U)$  is increasing in  $z_t$ , then in period  $t$  the consumer believes that the firm is clean with certainty. If  $\rho_t$  is such that  $E_t(U)$  is decreasing in  $z_t$ , then in period  $t$  the consumer believes that the firm is dirty with certainty. If  $\rho_t$  is such that  $E_t(U)$  is unaffected by changes in  $z_t$  the consumer randomizes in period  $t$ .*

**Theorem 2:** *If  $z_t$  is such that  $E_t(\pi_i)$  is increasing in  $y_b$ , then in period  $t$  the firm behaves clean with certainty. If  $z_t$  is such that  $E_t(\pi_i)$  is decreasing in  $y_b$ , then in period  $t$  the firm behaves dirty with certainty. If  $z_t$  is such that  $E_t(\pi_i)$  is unaffected by changes in  $y_t$  the firm randomizes in period  $t$ .*

Theorems 1 and 2 are important for two reasons. First, together they provide a straightforward method for determining a sequential equilibrium. Second, they clearly demonstrate the role played by reputation in determining the mixed strategies adopted by the consumer and the firm. From Theorem 1, we see that the consumer's strategy is directly dependent on the firm's reputation. From Theorem 2, we see that the firm's strategy is indirectly tied to its reputation through its effect on the consumer's strategy. These relationships make intuitive sense. The best the consumer can do vis-à-vis the firm is to base his strategy on the firm's reputation, which itself is determined by the firm's previous behavior. Knowing solely its own payoff matrix, the best the firm can do vis-à-vis the consumer is to base its strategy on the probabilities associated with the consumer's mixed strategy. The following examples will help illuminate this intuition.

#### 4. Examples of A Sequential Equilibrium

Table 2 describes the 9 possible strategies that a consumer and firm might follow. These strategies result in a total of 81 possible stage games that might be played between the two. For example, the consumer might select her strategy A (the firm is always expected to be dirty) and the firm might select its strategy A (always behave dirty), resulting in stage game AA; or the consumer might select strategy B (the firm is always expected to be clean) and the firm might remain with strategy A, resulting in state game BA, etc.

[INSERT TABLE 2]

For the consumer, strategy C is most interesting. This is due to the fact that strategy C

best reflects a consumer's ability to adjust his beliefs in a way that is consistent with new information.<sup>15</sup> For the firm, strategies A and C are most interesting. Strategy A reflects a dominant strategy to behave dirty. Under this strategy, the firm is a priori least likely to alter its behavior in repeated play, and thus least likely to be concerned about its reputation. Strategy C reflects more of a willingness on the part of the firm to alter its behavior in a manner that is consistent with the consumer's beliefs. In this section, we therefore restrict our attention to games CA and CC.<sup>16</sup>

### 3.1 Game CA

Suppose the period-by-period equilibrium payoffs for each agent are as expressed in Table 3.<sup>17</sup> Accordingly, the firm's dominant strategy is to behave dirty. However, the consumer does not have a dominant strategy. He believes that the firm is dirty when it plays dirty, and that the firm is clean when it plays clean. Table 3 may now be used to calculate the sequentially

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15 Strategies A, B, E, G, and I imply either no or only partially consistent adjustment on the part of the consumer. Strategies D, F, and H imply adjustments that are either wholly or partially inconsistent with new information. The no-adjustment strategies are trivial in the context of this model. While they may impart some interesting results from a purely theoretical perspective, neither a strong intuitive nor empirical argument seems to support the partially consistent and partially inconsistent adjustment strategies. For example, it is unclear why a consumer who uses new information to update his decision-making process would ever make wholly inconsistent adjustments in his choice of which firms to reward and punish. Similarly, it is implausible that this same type of consumer would be indifferent when the firm behaves dirty, but then believe that the firm is clean when it behaves clean. To the contrary, Strategy C is both intuitively appealing and supported by some empirical evidence (OECD, 1997 and Konar and Cohen, 1997). In addition, Strategy C is consistent with Theorem 1 above.

16 Strategy D for the firm is also of interest. It reflects a willingness on the part of the firm to alter its behavior in a manner that is inconsistent with the consumer's beliefs. Due to space restrictions, we do not present results for game CD. However, these results are available from the author upon request.

17 These payoff values have been arbitrarily selected for the purpose of example only. They represent the minimum discrete values that are necessary for game CA. The results in this section do not qualitatively change if minimum continuous values are used to establish the respective games CA and CC.

rational strategies for each agent.

[INSERT TABLE 3 HERE]

Using (2b), the firm's expected final-period  $T$  payoff is:

$$E_T(\pi) = z_T[y_T(0) + (1 - y_T)(1)] + (1 - z_T)[y_T(0) + (1 - y_T)(1)] = 1 - y_T. \quad (6)$$

Since  $E_T(\pi_i)$  is decreasing in  $y_T$  for any value of  $z_T$ , we know by Theorem 2 that  $y_T = 0$ . Thus, the firm behaves dirty in the final period with certainty.

Using (2a), the consumer's expected final-period  $T$  payoff is:

$$E_T(U) = z_T[\rho_T(1) + (1 - \rho_T)(0)] + (1 - z_T)[\rho_T(0) + (1 - \rho_T)(1)] = 1 + z_T(2\rho_T - 1) - \rho_T. \quad (7)$$

Using Theorem 1 and (7), if  $\rho_T > 1/2$  the consumer plays  $z_T = 1$  (i.e. he believes the firm is clean with certainty); if  $\rho_T < 1/2$  he plays  $z_T = 0$  (i.e. believes the firm is dirty with certainty); and if  $\rho_T = 1/2$  the consumer is indifferent about  $z_T$ . This result is conveniently expressed as:<sup>18</sup>

(8)

Taking these possible outcomes into account, the expected values to the firm and the consumer, respectively, of playing the game in final period  $T$  are:<sup>19</sup>

$$E_T(\pi) = 1 \quad (9a)$$

$$E_T(U) = \max(\rho_T, 1 - \rho_T). \quad (9b)$$

In period  $T-1$ , the firm's expected two-period payoff is:

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<sup>18</sup> The result for  $z_T = 1/2$  is really the result for  $E_T(z_T)$ , since  $0 \leq z_T \leq 1$  when  $\rho_T = 1/2$ .

<sup>19</sup> Note that when the consumer believes the firm is clean with certainty, and thus sets  $z_T = 1$ , (7) reduces to the first term in the max operator of (9b). When the consumer believes the firm is dirty with certainty, and thus sets  $z_T = 0$ , (7) reduces to the second term in the max operator of (9b). When the consumer is indifferent, and thus sets  $0 < z_T < 1$ , (7) reduces to a value between the two terms in the max operator (9b).

$$E_{T-1}(\pi) = z_{T-1}[y_{T-1}(0) + (1 - y_{T-1})(1)] + (1 - z_{T-1})[y_{T-1}(0) + (1 - y_{T-1})(1)] \\ + y_{T-1} E_T[\pi(T, z_T, y_T)] + (1 - y_{T-1})(1).$$

The final term of this equality reflects the fact that if the firm behaves dirty in period  $T-1$ , which it does with probability  $(1 - y_{T-1})$ , then its reputation is blown. The consumer therefore expects the firm to behave dirty in the final period, and the best that the firm can do is to behave dirty, thus receiving a payoff of  $1$ . The second-to-last term is the probability of the firm behaving clean in  $T-1$ , and thus collecting the associated payoff  $\pi(T, z_T, y_T)$  in period  $T$ . The expression reduces to:

$$E_{T-1}(\pi) = 2 + y_{T-1}(E_T(\pi) - 2). \quad (10)$$

The consumer's expected two-period payoff is:

$$E_{T-1}(U) = z_{T-1}[q_{T-1}(1) + (1 - q_{T-1})(0)] + (1 - z_{T-1})[q_{T-1}(0) + (1 - q_{T-1})(1)] \\ + q_{T-1} E_T(U) + (1 - q_{T-1})(1)$$

where the final term reflects the fact that if the consumer does not believe the firm is clean in period  $T-1$  (i.e. the firm's reputation is blown), then his payoff in the final period is  $1$  (see Table 3). The expression reduces to:

$$E_{T-1}(U) = 2 + z_{T-1}(2q_{T-1} - 1) - 2q_{T-1} + q_{T-1} E_T(U) \quad (11)$$

Using Theorem 2 and (10), we see that the firm's dominant strategy is  $y_{T-1} = 0$ , since  $E_T(\pi) = 1$ . Using Theorem 1 and (11), we also see that  $z_{T-1} = 1$  only when  $q_{T-1} > 1/2$ , and that  $0 \leq z_{T-1} \leq 1$  when  $q_{T-1} = 1/2$ . Assuming the consumer believes the firm will behave clean in period  $T-1$  with probability<sup>20</sup>

(12)

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<sup>20</sup> This expression simply defines  $y_{T-1}$  as the odds ratio in favor of the firm behaving clean in period  $T-1$ . Recall that the consumer does not know (10) and thus does not know that the firm's dominant strategy in period  $T-1$  is to behave dirty.



then given that  $q_{T-1} = \rho_{T-1} + (1 - \rho_{T-1})y_{T-1}$ ,  $\rho_{T-1} > 1/4$  ensures  $q_{T-1} > 1/2$ . In other words, given the hypothetical payoffs in Table 2, as long as the firm's reputation is such that the probability is greater than  $1/4$  that the firm will behave clean in period  $T-1$  given that it has behaved clean up to that point, the consumer will believe that the firm is clean in  $T-1$  with certainty. Using (1) and (12),  $0 < \rho_{T-1} \leq 1/2$  implies that  $\rho_T = 1/2$ , which implies that  $0 < z_T < 1$ , and  $\rho_{T-1} > 1/2$  implies that  $\rho_{T-1} = \rho_T$ , which implies  $z_T = 1$ . We therefore see that the consumer is either indifferent or believes with certainty that the firm is clean in period  $T$ , depending upon the firm's reputation in period  $T-1$ .

This solution can be extended to earlier periods by recognizing that

$$E_{T-j+1}(\pi) = j + y_{T-j+1}(E_{T-j+2}(\pi) - j), \quad j = 3, 4, \dots, T \quad (13a)$$

$$E_{T-j+1}(U) = j + z_{T-j+1}(2q_{T-j+1} - 1) - jq_{T-j+1} + q_{T-j+1}E_{T-j+2}(U), \quad j = 3, 4, \dots, T \quad (13b)$$

Recursively solving for  $E_{T-j+2}(\pi)$  shows that  $E_{T-j+2}(\pi_i) - j = -1$ , which, when accounting for our earlier results for periods  $T-1$  and  $T$ , implies that

$$y_{T-j} = 0, \quad j = 0, 1, \dots, T-1 \quad (14a)$$

$$E_{T-j}(\pi) = j + 1, \quad j = 0, 1, \dots, T-1 \quad (14b)$$

Using (14a), and the previous results for periods  $T-1$  and  $T$ , we see that

$$, \quad j = 0, 1, \dots, T-1 \quad (15)$$

where the second equality results directly from (1) and (12).<sup>21</sup> Equations (14) and (15) may be

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21 Similar to footnote 18, the result for  $z_{T-j} = 1/2$  is really the result for  $E_{T-j}(z_{T-j})$ , since  $0 \leq z_{T-j} \leq 1$  when  $q_{T-j} = 1/2$  and when  $\rho_{T-j} > 1/2$ .

summarized in the following proposition.

**Proposition 1:** *If payoffs in the stage game are such that a consumer has beliefs which are consistent with the firm's behavior, and the firm's dominant strategy is to behave dirty, then the firm will behave dirty every period in a finite game.*

Proposition 1 implies that when a dirty firm's dominant strategy is to behave dirty, a repeated game between the firm and a consumer - where the consumer builds a reputation about the firm based on the firm's past behavior - will not induce the firm to behave clean in any period. Thus, information provision is not an effective regulatory instrument when conditions are such that the consumer mixes has consistent beliefs about the firm's behavior, and behaving dirty is the firm's dominant state-game strategy.

This result extends to multiple periods Cavaliere's (2000) finding for a two-period game played between a monopolist and a consumer. In his model, Cavaliere adopts game CA and finds that under certain circumstances the firm may revert to clean production in the first period in order to gain a reputation as a clean firm; a reputation that it can then exploit by behaving dirty in the second period. What drives his result, and thus distinguishes it from Proposition 1 above, is the assumption in Cavaliere's model that the consumer builds prior beliefs not only on whether or not the monopoly firm will behave dirty, but also on whether or not the firm's production is constrained a priori to be clean, say by the threats of potential entry or environmental regulation. As long as the probability of this constraint is nonnegative, and the consumer incurs a loss when he incorrectly guesses that the firm will behave clean, the probability that an unconstrained firm will behave clean is also nonnegative. Therefore, what Proposition 1 implies in relation to Cavaliere's model is that without an additional potential constraint on its production behavior, the firm has no incentive in game CA to behave clean in

any period.

### 3.2 Game CC

Suppose the period-by-period equilibrium payoffs for each agent are as expressed in Table 4. Accordingly, both the firm's and the consumer's strategies are consistent. As in the previous game, the consumer believes that the firm is dirty when it behaves dirty, and believes that the firm is clean when it behaves clean. Similarly, the firm's optimal strategy is to behave dirty when it is believed dirty and to behave clean when it is believed clean. Table 4 may now be used to calculate the sequentially rational strategy for the firm.<sup>22</sup>

[INSERT TABLE 4 HERE]

Using (2b) and reducing, the firm's expected final-period  $T$  payoff is:

$$E_T(\pi) = I - z_T + y_T(2z_T - I). \quad (16)$$

Using Theorems 1 and 2 we see immediately that the firm's period  $T$  strategy is:<sup>23</sup>

$$, \quad (17)$$

and its period  $T$  payoff is:

$$. \quad (18)$$

Therefore, from (17) we see that the firm will behave clean in period  $T$  with probability  $y_T > 0$

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<sup>22</sup> Since in this game the consumer's strategy is the same as in the previous game's, we report only the firm's strategy and payoffs here.

<sup>23</sup> Similar to  $z_{T-j} = 1/2$  in (15),  $y_T = 1/2$  is really the result for  $E_T(y_T)$ , since  $0 \leq y_T \leq 1$  when  $z_T = 1/2$ .

when  $z_T \geq 1/2$ .

In period  $T-1$ , the firm's expected two-period payoff is:

$$E_{T-1}(\pi_i) = 2 - z_{T-1} + y_{T-1}(2z_{T-1} + E_T(\pi_i) - 2). \quad (19)$$

It is straight-  
forward to  
show that the  
firm's

strategy in period  $T-1$  is:

$$(20)$$

and its associated two-period payoff in  $T-1$  is:

$$(21)$$

Solving recursively for the firm's strategy in periods  $T-j$ ,  $j = 2, 3, \dots, T-1$  we see that

$$(22)$$

The firm's expected  $j$ -period payoff over all periods  $j$  is therefore:

$$E_{T-j}(\pi) = j + 1 - z_{T-j} + y_{T-j}(2z_{T-j} - (j+1) + E_{T-j+1}(\pi)), \quad j = 0, 1, \dots, T-1 \quad (23)$$

These results are summarized in the following proposition.

**Proposition 2:** *If payoffs in the stage game are such that both the consumer and the firm have beliefs which are consistent with each others' behaviors, then the firm has a positive probability of behaving clean in each period of a finite game.*

Proposition 2 might therefore be thought of as a realistic lower bound on what the stage game strategy of the firm must be before it will have a nonnegative probability of behaving clean in a finitely repeated game. We say “realistic” under the assumption that publicly provided information can sustain an equilibrium where the consumer uses a mixed strategy that is consistent with the firm’s behavior, and that the firm simultaneously adopts a mixed strategy that is consistent with the consumer’s beliefs. Further, it seems doubtful that a firm will behave clean with a positive probability in any equilibrium for a repeated game that is predicated on the firm having a dominant strategy of behaving dirty in the stage game. It also seems unrealistic to assume that a consumer and a firm would be willing to follow ‘believe clean’ and ‘behave clean’ as respective dominant strategies. Thus, not only are the consistent mixed strategies of Proposition 2 most realistic, they also result in the firm caring enough about its reputation to behave clean with a positive probability, even in the final period of a finite game with the consumer.

## 5. A Numerical Example

For this example, we assume that a consumer purchases private goods from two firms - firms 1 and 2 - to maximize her utility. Her preferences over these two goods ( $x_1$  from firm 1 and  $x_2$  from firm 2) and the given aggregate amount of net emissions of a common pollutant produced by the two firms,  $g$ , are represented by:

$$U = \varphi x_1 + (1 - \varphi)x_2 - 0.5g, \quad (24)$$

subject to the budget constraint:

$$Y + t(\pi_1 + \pi_2) + w(l_1 + l_2) = p_1x_1 + p_2x_2. \quad (25)$$

where  $Y$  is an initial endowment,  $t$  is the dividend rate on firm profits,  $w$  is the equilibrium wage rate, and  $l_i$  and  $p_i$  are the equilibrium amount of inelastically supplied labor to firm  $i$  and output price, respectively,  $i=1,2$ .

The utility weights  $\varphi$  are adjusted by the consumer to reflect information provided (say, by the regulator about the firm's level of cleanliness) at the beginning of the supergame. For example, if the consumer learns through publicly provided information that firm 1 has become cleaner relative to firm 2, *ceteris paribus*,  $\varphi$  will increase. The consumer therefore responds to the information by shifting more weight in her preference function to  $x_1$  and away from  $x_2$ . This information might be "structured", whereby a regulator releases it as part of a clearly articulated strategy, rather than "unstructured" information of the type found in the popular press on a more ad hoc basis (Foulon et al., 2000). Or, in terms of the eco-labeling programs mentioned in the Introduction, the regulator might mandate Type I labels as opposed to Types II and III.<sup>24</sup> The externality  $g = \sum_i x_i - \sum_i a_i$ , where  $a_i$  is firm  $i$ 's level of pollution abatement.

Firms 1 and 2	choose their respective $l_i$ and $a_i$
to maximize their profit	functions,

$$\pi_1 = p_1x_1 - wl_1 - \tau_1g - a_1^2 \quad (26a)$$

(26b)

---

24 As shown by Shapiro (1983), a parameter such as  $\varphi$  can be conveniently thought of as a policy variable that represents the extent of informational problems in the economy, and which can be influenced by the information-provision activities of a regulator.

subject to decreasing returns-to-scale technology in output, and convex costs in abatement  $a_i$ .<sup>25</sup> For this example, firm 1 is assumed ‘time inconsistently’ clean by “self-taxing” itself at  $\tau_1 > 0$  per unit of aggregate emissions, and it internalizes the effects that both its output and abatement activities (i.e. its choice set) have on  $g$  in each period. This self-tax represents an additional expense that firm 1 incurs as a result of being more socially responsible and thus distinguishing itself as a “green” firm.<sup>25</sup> Firm 2 may behave dirty or clean in any given period. If dirty, then firm 2 places no self-tax on the level of aggregate emissions. Likewise, it does not internalize the effects on  $g$  of its output and abatement. If clean, firm 2 mimics firm 1 - it self-taxes at rate  $\tau_1 > 0$  and internalizes the effects on  $g$  of its output and abatement.

Table 5 provides the specific parameter values adopted for this example. Given these parameter values, we are able to solve for stage-game equilibrium values for the set of endogenous variables  $\{U, \pi_1, \pi_2, x_1, x_2, l_1, l_2, g, p_1, p_2, a_1, a_2, \lambda\}$ , where  $\lambda$  is the shadow value on (29).<sup>26</sup>

[INSERT TABLE 5 HERE]

We consider three information scenarios. These scenarios are delineated by the different values of  $\phi$  chosen by the consumer. In the first scenario - for sake of example called the “unstructured” information scenario - we assume that the consumer does not have available certified information about firm-specific emissions, and thus does not greatly reward (in a

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<sup>25</sup> The self-tax used in this example has the same effect in distinguishing a clean from a dirty firm as would voluntary abatement effort. Further, it enables a simpler solution to the stage-game equilibrium primarily because it reduces the number of endogenous variables in the system..

<sup>26</sup> *Mathematica (version 3)* was used to solve the system represented by equations (24) - (26) and Tables 5 and 6. The output for each of the scenarios presented in this section is available upon request from the author.

relative sense) firm 2 for behaving clean.<sup>27</sup> Similarly, the consumer does not severely punish the firm 2 for behaving dirty. In this case, when firm 2 behaves clean and he believes firm 2 is clean (cell  $(\pi_2^2, U^2)$  in Table 1), the consumer nonetheless chooses a relatively high value for  $\varphi$  (thus providing little reward to firm 2 in a relative sense). However, when firm 2 behaves dirty and he believes firm 2 is dirty (cell  $(\pi_2^3, U^3)$  in Table 1), the consumer chooses a relatively low value for  $\varphi$  (thus providing little punishment to firm 2).

In the second scenario - called the “intermediate” information scenario - we assume that the consumer presumably has available some mix of structured and unstructured information about firm-specific emissions, and thus provides a larger reward to firm 2 than in the previous scenario for behaving clean, and similarly punishes firm 2 more severely for behaving dirty. In the third scenario - called the “structured” information scenario - we assume that the consumer has available the highest quality information possible about firm-specific emissions. He thus greatly rewards firm 2 for behaving clean (again, in a relative sense), and greatly punishes firm 2 for behaving dirty. In this case, the consumer chooses a relatively low value for  $\varphi$  when he believes firm 2 is clean and firm 2 behaves clean (thus providing firm 2 with a high reward), and he chooses a relatively high value for  $\varphi$  when he believes firm 2 is dirty and firm 2 behaves dirty (thus providing firm 2 with a high punishment).

The specific values of  $\varphi$  that we use to delineate these three scenarios are provided in Table 6. Recall that cell  $(\pi_2^2, U^2)$  corresponds to the outcome when the consumer believes firm 2

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27 Recall that “unstructured” information is of the type found in the popular press on a more ad hoc basis (Foulon, et al., 2000). Of course, this scenario could evolve for another reason - the consumer has “structured” information available, but for whatever reason chooses not to fully utilize it. Naming scenarios in this fashion is common in the literature. For example, Kreps and Wilson (1982a) delineate between “weak” and “strong” monopolists based on different payoff matrices.



is clean and firm 2 in fact behaves clean that period. This might be termed the “reward” cell. Thus, as the value of  $\varphi$  decreases in his utility function, the consumer is effectively rewarding firm 2 more and more for what he believes is clean behavior. Likewise, recall that cell  $(\pi_2^3, U^3)$  corresponds to the outcome when the consumer believes firm 2 is dirty and firm 2 in fact behaves dirty that period. This might be termed the “punishment” cell. Thus, as the value of  $\varphi$  increases in his utility function, the consumer is effectively punishing firm 2 more and more for what he believes is dirty behavior. Finally, for both scenarios we assume that the value of  $\varphi$  associated with cell  $(\pi_2^1, U^1)$  is constant at 0.48, and that the value of  $\varphi$  associated with cell  $(\pi_2^4, U^4)$  is 0.5.<sup>28</sup>

[INSERT TABLE 6 HERE]

Before presenting the results for each of the three scenarios, it is instructive to briefly examine the consumer’s and firm 2’s sequential strategies that result for one of the scenarios. Consider the Unstructured Information scenario. Given the parameter values contained in Tables 5 and 6, Table 7 presents the consumer’s and firm 2’s corresponding equilibrium payoffs for this scenario.<sup>29</sup> Note that in this game, the consumer’s dominant strategy is to believe that firm 2 is dirty, while firm 2’s optimal strategy is to behave dirty when believed dirty and to behave clean when believed clean (i.e. game AC in Table 2).

[INSERT TABLE 7 HERE]

Using (2b), firm 2’s expected final-period  $T$  payoff is:

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28 The values for  $\varphi$  that correspond to cells  $(\pi_2^2, U^2)$  and  $(\pi_2^3, U^3)$  were purposefully chosen to be in a tight band around 0.5. Obviously, as this band widens the corresponding magnitudes of the stage game payoffs that distinguish the three information scenarios also widen.

29 Because both the consumer’s and firms’ respective maximization problems are quasi-concave programs, sufficient second-order conditions for optimality are naturally met.

$$\begin{aligned}
E_T(\pi_i) &= z_T[y_T(194.42) + (1 - y_T)(194.41)] + (1 - z_T)[y_T(179) + (1 - y_T)(187)] \\
&= 187 + 7.41z_T + y_T(8.01z_T - 8), \quad (27)
\end{aligned}$$

which implies

(28)

Thus, as (28) indicates, even without common knowledge it is highly unlikely that firm 2 will behave clean in period  $T$ . Using (2a), the consumer's expected final-period  $T$  payoff is:

$$\begin{aligned}
E_T(U) &= z_T[\rho_T(0.03) + (1 - \rho_T)(0.01)] + (1 - z_T)[\rho_T(0.05) + (1 - \rho_T)(0.02)] \\
&= z_T(-0.01\rho_T - 0.01) + 0.06\rho_T + 0.02, \quad (29)
\end{aligned}$$

which implies  $z_T = 0$ , in turn implying that  $y_T = 0$  and  $E_T(\pi_2) = 187$  in equilibrium. It is straightforward to show that this same result occurs in each prior period. Thus,

,

implying that in equilibrium  $z_t = 0$  and  $y_t = 0 \square t$ . In other words, the sequential equilibrium that evolves from this repeated game is the consumer believing firm 2 is behaving dirty in every period, while firm 2 in fact behaves dirty. This suggests that unstructured information may not be strong enough to move the consumer and a dirty firm away from noncooperation.

Table 8 presents firm 2's sequential equilibria strategies for each of the three information scenarios considered in this section. These strategies were determined using exactly the same approach as that used above for the Unstructured Information scenario. In contrast with the Unstructured Information scenario, both the Intermediate and Structured Information scenarios

induce firm 2 to behave clean in each period  $t$  of the repeated game. This marked shift in firm 2's behavior is predicated on a relatively small change in the consumer's choice of  $\varphi$ , indicating that a dirty firm's emissions may be very responsive to how consumers utilize publicly provided information. This is further good news for those nations considering a shift away from the regulator-centric paradigm of pollution control.

[INSERT TABLE 8]

Additional results from our simulations of the calibrated model concern the levels of aggregate emissions and consumer welfare as the reward/punishment scheme adopted by the consumer changes. Table 9 contains the period-by-period aggregate emissions and welfare levels associated with each of three scenarios presented in this paper. Thus, aggregate emissions and consumer welfare over  $T$  periods is  $T$  times the levels reported in Table 9.

[INSERT TABLE 9 HERE]

Aggregate emissions steadily decline and consumer welfare steadily increases as we move from the unstructured to the structured information scenario. This pattern supports the hypothesis that stronger reward/punishment schemes adopted by consumers (based upon the provision of more and better information about firm-level emissions) leads to lower aggregate emissions. We therefore find no support for the argument made by Mattoo and Singh (1994) that increased provision of public information can lead to increased emissions.<sup>30</sup>

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<sup>30</sup> Mattoo and Singh base their analysis upon the peculiar condition that equilibrium can admit excess demand and supply in differentiated markets as long as demand and supply are balanced in the aggregate. Proceeding from such a condition it is tautological that emissions will tend to increase if there continues to be excess demand in the market for the dirty good after the provision of public information. But, then, this is not necessarily a consequence of the provision of public information.

## **6. Summary and Policy Implications**

The preceding analysis has demonstrated that consumers' use of information to form reputations of dirty firms is a potentially powerful tool (or, "market mechanism") in controlling pollution. When a consumer and a firm each follow strategies that are consistent with each other's behaviors, we find that a firm which has the option of behaving dirty (i.e. it may choose not to internalize its contribution to an aggregate externality) nonetheless has a positive probability of playing clean in each period of a finite game. What drives this result is the two-fold assumption that consumers in fact utilize information provided to them, say by a regulatory agency, and that firms care about their environmental reputations. The latter assumption is highly plausible, especially as more and more information is made public about firms' environmental performances, and environmental problems become more and more a concern nationwide. The former assumption, however, is not as plausible.

Without a concerted effort on the part of regulatory agencies such as the EPA and the state Departments of Environmental Quality (DEQ's) to both provide consumers with information and assist them in using it, it is doubtful that enough consumers can provoke dirty firms into self-regulation simply by force of reputation. Consumers will require more information than that presently provided by the EPA and the various state DEQ websites; particularly information about smaller firms than those typically reported on, and information concerning a wider scope of pollutants. Further, the information will have to be disseminated in more accessible formats, such as through a product labeling scheme similar to that used in several OECD countries, or through other forms of mass advertising.

Perhaps the most encouraging example in the U.S. of how reputations are being formed among the general public is the social-investment movement. Total assets under management of

social-investment mutual funds, and the number of such funds themselves, has skyrocketed during the past few years. In essence, these funds act as clearinghouses of information for investors, so that investors are not required to invest time themselves in building their own reputations of dirty firms. In this case, firms are induced to care about their reputations through input-market effects, rather than through product-market effects. One frontier for future research is therefore to continue the investigation of the effectiveness of a firm's reputation among investors in inducing firms to self-regulate their pollution emissions, along the lines of Konar and Cohen (1997). The main question addressed in this paper would then be re-worded as, "To what extent must *investors* reward and punish dirty firms before the firms will choose self-regulation as their dominant strategies?" In the end, reputations formed by investors may be a more cost-effective means of inducing self-regulation than those formed by consumers. But cost-effectiveness itself is ultimately a frontier of future empirical research. Certainly, if consumers' reputations are to have a similar effect, some kind of product-market clearinghouse will have to be established to facilitate the dissemination of environmental information, as it has for input markets.

Perhaps the most important frontier for future research is an empirical investigation of this paper's theoretical propositions. For instance, while it is important to know that a consumer's reward/punishment scheme does not necessarily have to be strong - in a theoretical sense - in order to induce a dirty firm to become clean (e.g. based strictly on "structured" information, as in Section 5 of this paper), it is quite another to find empirical justification for such a claim. To our knowledge, a rich enough data set that tracks consumer choices between clean and dirty firms over time does not yet exist. Although it is a priori difficult to classify current consumer use of the TRI data as either "weak" or "strong," it seems reasonable to assume

that consumers are not yet making strong use of the data, no matter how strength is defined.

However, if in fact there exists a negative correlation between the passage of time (as a proxy for reputation) on the one hand, and firm emissions on the other, then this might suggest that strong reward/punishment schemes on the part of consumers are not necessarily required to change dirty firm behavior.

**Table 1.** The Model's Strategic Form.

<b>Firm</b>		<b>Consumer</b>	
		Believes firm is dirty	Believes firm is clean
	Behaves clean	$(\pi^1, U^1)$	$(\pi^2, U^2)$
	Behaves dirty	$(\pi^3, U^3)$	$(\pi^4, U^4)$

**Table 2.** The Possible Strategies for the Consumer and the Firm.

<b>Consumer</b>			<b>Firm</b>	
<u>Strategy</u>	<u>Description</u>		<u>Strategy</u>	<u>Description</u>
A	Always believe firm is dirty.		A	Always behave dirty.
B	Always believe firm is clean.		B	Always behave clean.
C	Believe firm is dirty when it behaves dirty, and it is clean when it behaves clean.		C	Behave dirty when believed dirty, and behave clean when believed clean.
D	Believe firm is clean when it behaves dirty, and it is dirty when it behaves clean.		D	Behave dirty when believed clean, and behave clean when believed dirty.
E	Indifferent when firm behaves dirty, and believe firm is clean when it behaves clean.		E	Indifferent when believed dirty, and behave clean when believed clean.
F	Indifferent when firm behaves dirty, and believe firm is dirty when it behaves clean.		F	Indifferent when believed dirty, and behave dirty when believed clean.
G	Indifferent when firm behaves clean, and believe firm is dirty when it behaves dirty.		G	Indifferent when believed clean, and behave dirty when believed dirty.
H	Indifferent when firm behaves clean, and believe firm is clean when it behaves dirty.		H	Indifferent when believed clean, and behave clean when believed dirty.
I	Complete indifference.		I	Complete indifference.

**Table 3.** Stage Game CA Payoffs for the Consumer and Firm.<sup>31</sup>

<b>Firm</b>		<b>Consumer</b>	
		Believes firm is dirty	Believes firm is clean
	Behaves clean	$(0, 0)$	$(0, 1)$
	Behaves dirty	$(1, 1)$	$(1, 0)$

**Table 4.** Stage Game CC Payoffs for the Consumer and Firm.

		<b>Consumer</b>	
		Believes firm is dirty	Believes firm is clean
	Behaves clean	$(0, 0)$	$(1, 1)$
<b>Firm</b>	Behaves dirty	$(1, 1)$	$(0, 0)$

**Table 5.** Parameter Values.

<b>Parameters</b>	<b>Values</b>
$\alpha$	1
$t$	0.75
$\tau_l$	0.05

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<sup>31</sup> Recall that the first number in the parentheses in each cell corresponds to the firm's payoff, while the second number in the parentheses corresponds to the consumer's payoff.



$Y$	100
$w$	1

**Table 6.** Values for  $\varphi$ .

	Scenario		
	Unstructured Info.	Intermediate Info.	Structured Info.
$(\pi^2, U^2)$	0.50	0.48	0.46
$(\pi^3, U^3)$	0.51	0.52	0.55

**Table 7.** Stage Game Payoffs Under the Unstructured Information Scenario.

		Consumer	
		Believes firm is dirty	Believes firm is clean
<b>Firm</b>	Behaves clean	$(179, 0.05)$	$(194.42, 0.03)$
	Behaves dirty	$(187, 0.02)$	$(194.41, 0.01)$

**Table 8.** Simulation Results for Firm 2's Sequential-Equilibrium Strategies.

<u>Information Scenario</u>	<u>Firm 2's Strategy</u>
Unstructured	Behave dirty in each period $t$ .
Intermediate	Behave clean in each period $t$ .

Structured	Behave clean in each period $t$ .
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**Table 9.** Simulation Results for Firm 2's Period-By-Period  
Level of Pollution Emissions and Consumer Welfare.

<u>Information Scenarios</u>	<u>Firm 2's Period-by-Period Level of Emissions</u>	<u>Consumer Welfare</u>
Unstructured	27.93	0.02
Intermediate	27.86	0.05
Structured	27.80	0.11

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